TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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COMPARISON OF STRESS-STRAIN CURVES OBTAINED

BY SINGLE-THICKNESS AND PACK METHODS

By D. A. Paul, F. M. Howell, and H. E. Grieshaber
Aluminum Company of America

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SUMMARY

An apparatus for supporting a single thickness of
sheet against buckling so that its compressive yield
strength can be determined by the single-thickness method
is described. The results obtained with the apparatus
are compared with those obtained on the same material by
the pack method, and the results obtained in compression
by the single-thickness and pack methods are compared with
those obtained on large solid specimens of such dimensions
that they did not require lateral restraint.

The results showed that the compressive yield
strength of thin sheet metals could be determined within
acceptable limits by the single-thickness method. The
apparatus, which was designed and used by the Aluminum
Company of America, is suitable for determining yield
strengths of aluminum-alloy sheet 0.020 inch and greater
in thickness.

INTRODUCTION

Since its development in 1933 at the National Bureau
of Standards the "pack" method has been satisfactorily
used for determining the compressive yield strength of
thin metallic materials. (See reference 1.) The main
disadvantages of this method are the high cost of machin-
ing the specimens and the length of time required to set
up the specimen in the testing machine because of the
large number of steel pins that must be individually ad-
justed to restrain the specimen laterally during a test.
In order to eliminate some of the disadvantages of the
pack method Mr. W. P. Montgomery of the Vought-Sikorsky
Aircraft Corporation proposed a scheme for testing a single
thickness of sheet. Following Mr. Montgomery's suggestion,

the Aluminum Research Laboratories designed and construct-
ed a slightly modified device for supporting a single
thickness of sheet against buckling so that its compres-
sive yield strength could be determined.

Both the pack and the single-thickness methods are
based on the supposition that they will give a compressive
yield strength the same as that obtained from a solid com-
pact specimen of such dimensions that it need not be rein-
forced against lateral buckling. In the original investi-
gation of the pack test at the National Bureau of Stand-
ards it was shown, by tests of steel, brass, and an alumin-
um alloy, to give compressive yield strengths comparable
with those obtained on solid specimens. Such a comparison
is also desirable in the case of the single-thickness
test.

This report describes the apparatus and compares the
results obtained in compression on single-thickness speci-
mens, using the single-thickness method, with those obtained
by the pack method and with those obtained on large solid
specimens with no lateral restraint.

MATERIAL

The specimens used in these tests were taken from
24S-T aluminum alloy flat sheet 0.020 inch and 0.040 inch
thick and from 17S-T aluminum alloy plate 5/8 inch thick.
The tensile properties of the sheet, as determined by the
New Kensington Works laboratory (P.T. no. K101440-C) were
as follows:

Lot [1]	Nominal thickness (in.)	Tensile strength (lb/sq in.)	Yield strength (offset=0.2 percent) (lb/sq in.)	Elongation in 2 in. (percent)
9431-W	0.020	73,120	63,100	14.5
9431-X	.020	72,810	55,800	15.0
3573-W	.040	71,130	52,300	17.5
3573-X	.040	69,210	46,100	21.0

[1] W, specimen cut with grain; X, cut across grain.

Results of tensile tests of the plate are given in table I.

The sheet was tested to compare the results obtained with the single-thickness and the pack methods; the plate was tested, primarily, to compare the results obtained, using single-thickness and pack specimens with results obtained on large solid specimens from the same material. These tests also provided additional comparisons between the single-thickness and the pack methods.

METHOD OF TEST

The compressive yield strength of each sheet sample was determined with and across grain, using both the pack and the single-thickness methods. Repeat tests were made with the single-thickness method. The pack specimens were composed of 21 pieces in the case of the sheet 0.020 inch thick and 11 pieces in the case of the sheet 0.040 inch thick. The single-thickness specimen is nominally 5/8 inch wide and 2 5/8 inches long. A group of such specimens can be machined together in the same manner as one pack specimen.

A total of seven specimens were cut from the plate, as shown by the sketch (fig. 1). Specimens T1 and T2 were tensile specimens and specimens C1 to C5 were compressive specimens. Specimens C1 and C2 were large compact specimens to be tested without lateral restraint and having a slenderness ratio (L/r) of 12. Specimen C3 was a pack specimen composed of 11 pieces, each 0.040 inch thick; specimens C4 and C5 were thin specimens 0.040 inch and 0.020 inch thick, respectively, to be tested with the single-thickness specimen apparatus. It may be noted from the sketch that specimens T1 and C1 were round and that the others were either square or rectangular. All these specimens were cut so that their longitudinal axes were parallel to the direction of rolling. The round specimens were the only ones from which the original surface was machined. Otherwise, the specimens were of the full thickness of the plate. The following tabulation shows the dimensions of the specimens cut from the 17S-T plate:

Spec-imen	Type of test	Type of specimen	Dimensions (in.)
T1	Tension	Rectangular ends, round reduced section	0.615 diameter (reduced section)
T2	-- do --	Rectangular ends, rectangular reduced section	5/8 x 1/2 (reduced section)
C1	Compression	Round[1]	5/8 diam. by $1\frac{7}{8}$ long
C2	----- do -----	Square[1]	5/8 x 5/8 x 2.16
C3	----- do -----	Pack - 11 pieces each	0.040 x 5/8 x $2\frac{1}{4}$
C4	----- do -----	Single-thickness	0.040 x 5/8 x $2\frac{5}{8}$
C5	----- do -----	Single-thickness	0.020 x 5/8 x $2\frac{5}{8}$

[1] Slenderness ratio $(L/r) = 12$

Figures 2, 3, and 4 are photographs showing the apparatus for holding a single-thickness specimen for a compression test. Figure 2 shows the various parts of which the apparatus is composed. These parts are the steel holder 1; the steel blocks 2 that support the spring clips 3, which in turn support the steel rollers 4; and one of the aluminum rods 5 that are placed in the adjustable eye-bars 6 to clamp the tensometers against the edges of the specimen.

Figure 3 shows the various parts assembled for a test. In the assembly of the apparatus the holder is placed on a smooth flat surface and the steel blocks supporting the rollers are placed in the holder. The specimen is placed in the holder and alined vertically. The holder, the steel blocks, and the specimen all rest on the smooth flat surface. The rollers are clamped firmly against the specimen, using the screws 7. The rollers then contact the specimen directly opposite one another on the two sides of the sheet and also bear against the steel blocks. The rollers are 0.093 inch in diameter and 7/16 inch long, with conical ends which are guided by the flexible brass spring clips 3.

As the rollers move during a test the spring clips move
outward on the conical bearing so that they do not re-
strain the downward movement of the rollers. Each steel
block supports 25 rollers spaced 0.10 inch center to cen-
ter. Calculations show that with this spacing aluminum-
alloy specimens with a minimum thickness of about 0.020
inch can be loaded to the compressive yield strength with-
out lateral buckling.

The specimen, with Huggenberger tensometers clamped
on each edge, is shown in the testing machine ready for
test in figure 4. Increments of stress are applied and
corresponding strains are measured until the compressive
yield strength of the material is exceeded.

Huggenberger tensometers were used on a 1/2-inch
gage length for measuring strains in the compression
tests. All the compression tests were made in the same
testing machine and with the same pair of tensometers.
The large compact compression specimens were tested in a
subpress placed between the heads of the testing machine.

DISCUSSION

Table II is a summary of the test results for the
specimens cut from the 24S-T flat sheet and shows a com-
parison of values of compressive yield strength as deter-
mined on a single thickness and as determined on a pack
made up of a number of thicknesses. The maximum variation
of the yield-strength values determined in repeat tests
by the single-thickness method was only about 2 percent
from the average values. In all but one case the average
compressive yield strength determined for the single-
thickness specimens is slightly less than that obtained
on a pack specimen. The average difference is about 1.3
percent. Compressive stress-strain curves have been plot-
ted for the specimens cut from the sheet samples and are
shown in figures 5 and 6. An examination of these curves
reveals no significant differences in the shapes of the
curves for the two types of specimen.

The compressive yield strengths obtained on the vari-
ous specimens cut from the 17S-T plate are summarized in
table I. The stress-strain curves from which the yield
strength values were selected are shown by figure 7. The

maximum variation from the average of any of these values
is only about 0.6 percent, and, because of this uniformity,
it seems permissible to conclude that the single-thickness
and pack methods give compressive-yield-strength values the
same as those obtained on large solid specimens.

    In the pack test the specimen on which strains are
measured is restrained against lateral expansion by pres-
sure of the adjoining specimens against its entire flat
surface; whereas, in the single-thickness test the speci-
men is restrained against lateral expansion only at the
line contact with the rollers. By the use of the pack
apparatus, lateral pressure is affected by some 30 screws
that are individually tightened; with the single-thickness
apparatus, only two screws are used to provide lateral re-
straint. Even though these two screws are tightened with
considerable torque, the total pressure exerted is un-
doubtedly less than that exerted by the large number of
individulally tightened screws in the pack test. It was
thought that this difference between the two methods might
have some effect upon the shape of the stress-strain curves
or upon the modulus-of-elasticity values and that deviation
curves for the stress-strain diagrams might indicate such
effects.

    The data obtained on the 17S-T plate have been con-
sidered in this manner, and figure 8 shows the deviation
curves corresponding to each of the stress-strain curves
shown by figure 7. Modulus-of-elasticity values have been
calculated, using the slopes of these curves to correct
the trial modulus, and the greatest variation from the av-
erage is 1.2 percent. These values and the proportional
limits indicated by the deviation curves are summarized
in table I. It is apparent that these data and the devi-
ation curves do not indicate any differences resulting
from differences between the two types of tests. In other
words, the pins used in the pack test and the rollers used
in the single-thickness test provide adequate support
against lateral buckling, but they do not restrain the
specimen to such an extent that the lateral force applied
affects the stress-strain properties. It is especially
interesting to note that the modulus of elasticity and
the proportional-limit values obtained on the single spec-
imen 0.020 inch thick (specimen C5) compare favorably with
those obtained on the larger compression specimens.

    Among the factors that contribute to the high cost
of making a pack compression test are the following:

1. The relatively large amount of material required, for some thin sheet as many as 21 pieces each about 5/8 inch by 2 1/4 inches

2. The time required to machine a pack on two edges and two ends with sufficient accuracy to produce good results

3. The time required to set up the specimen ready for test

4. The time required to obtain the stress-strain data

5. The time required to plot the stress-strain data

The single-thickness compression test offers considerable saving in the first three factors, but, of course, the time required to obtain the stress-strain data and to plot the data is unchanged. The cost of making a compression test of thin sheet metal, using either of the two methods considered, is very much greater than the cost of making the commercial routine inspection, laboratory tension test. In spite of this fact, however, the single-thickness method provides a very useful means of investigating the properties of thin sheet metals.

CONCLUSIONS

The results of this investigation may be summarized as follows:

1. The compressive yield strength of thin sheet metals can be determined within acceptable limits by the single-thickness method. The apparatus used in this investigation is suitable for determining yield strengths of aluminum-alloy sheet 0.020 inch and greater in thickness.

2. Because of substantial savings in the cost of preparing and testing the specimens, the single-thickness method would appear to have a definite advantage over the pack method.

3. Although the single-thickness specimen method described in this report is very useful for investigating

the compressive properties of thin sheet metals, its
present cost would appear to preclude its use as a routine
commercial inspection test.

Aluminum Research Laboratories,
      Aluminum Company of America,
            New Kensington, Penna., May 27, 1941.

REFERENCE

1. Aitchison, C. S., and Tuckerman, L. B.: The "Pack"
      Method for Compressive Tests of Thin Specimens of
      Materials Used in Thin-Wall Structures. Rep. No.
      649, NACA, 1939.

TABLE I

SUMMARY OF COMPRESSIVE AND TENSILE PROPERTIES OF SPECIMENS CUT FROM 5/8-THICK 17S-T PLATE

[Longitudinal axis of all specimens parallel to direction of rolling]

Spec-imen	Type of specimen [1]	Compressive properties			Tensile Properties			
		Yield strength (offset = 0.2 percent) (lb/sq in.)	Proportional limit (lb/sq in.)	Modulus of elasticity (lb/sq in.)	Tensile strength (lb/sq in.)	Yield strength (offset = 0.2 percent) (lb/sq in.)	Elongation (percent)	
							4D	2 in.
T1	Round				61,930	42,800	17.1	
T2	Rectangular				61,200	43,000		20.0
C1	Round	41,100	24,200	10,350,000				
C2	Square	40,800	22,200	10,540,000				
C3	Pack	41,200	22,300	10,470,000				
C4	Single-thickness	41,000	20,600	10,540,000				
C5	Single-thickness	41,100	22,200	10,500,000				

[1]See fig. 1.

TABLE II

RESULTS OF COMPRESSIVE YIELD STRENGTH DETERMINATIONS ON 24S-T ALUMINUM-ALLOY SHEET

(P.T. no. 101740-C)

Direction	Nominal thickness, (in.)	Specimen	Compressive yield strength (offset = 0.2 percent)			Variation of compressive yield strength obtained by single-thickness method from that obtained by pack method
			Single-thickness method		Pack method	
			(lb/sq in.)	Variation from average (percent)	(lb/sq in.)	(percent)
Longitudinal	0.020	A	51,500	+2.1		
		B	49,400	-2.1		
		Average	50,450		50,400	+0.1
Transverse	.020	A	55,500	-1.1		
		B	56,700	+1.1		
		Average	56,100		57,400	-2.3
Longitudinal	.040	A	43,900	+1.4		
		B	42,700	-1.4		
		Average	43,300		44,000	-1.6
Transverse	.040	A	48,000	-0.2		
		B	48,200	+0.2		
		Average	48,100		48,700	-1.2
					Average difference	-1.3

Fig. 1

C4 C5

C3

C2

C1

T2

T1

— DIRECTION OF ROLLING —

FIGURE 1.—SKETCH SHOWING LOCATION OF SPECIMENS CUT FROM $\frac{5}{8}''$ THICK 17S-T PLATE.
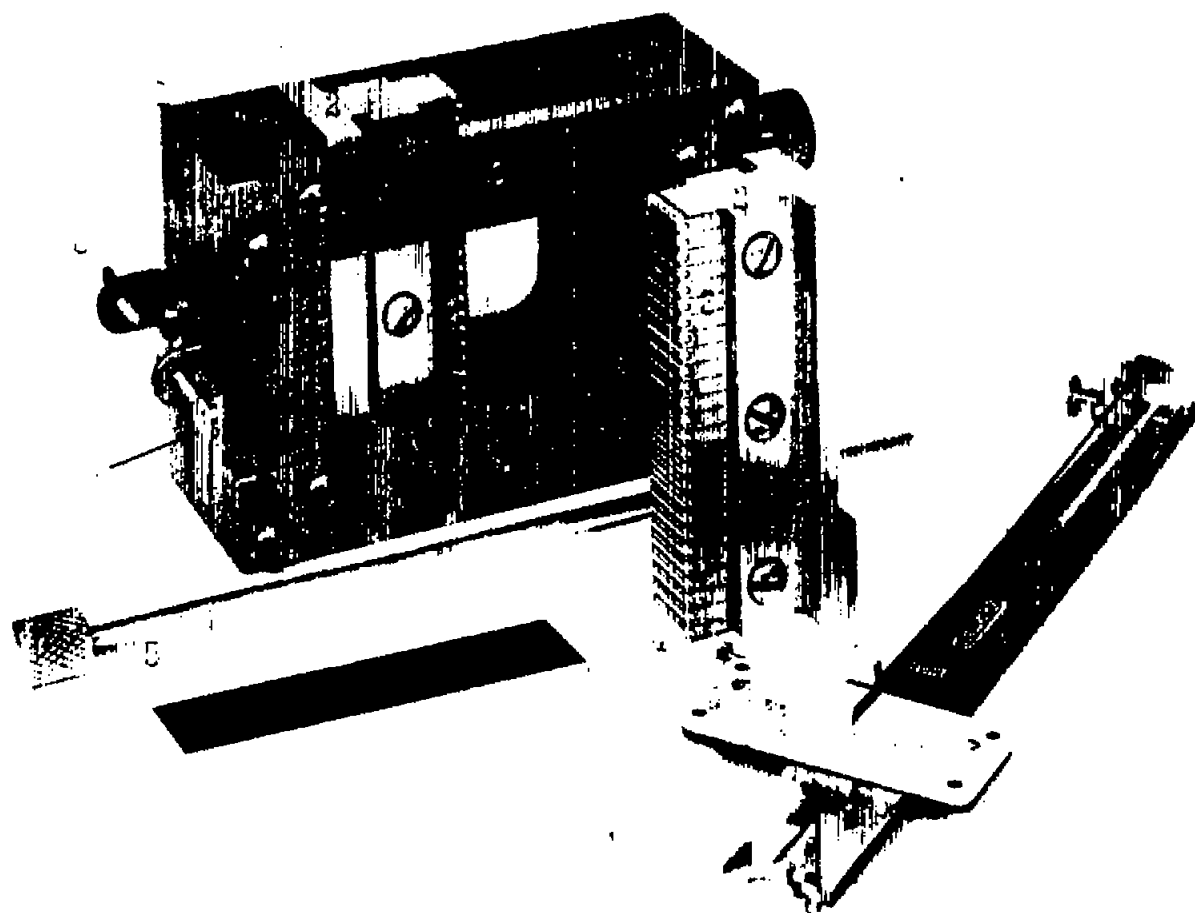
$\frac{5}{8}''$

Fig. 1

Figure 2.- Parts of device for making compression tests of single thicknesses
of sheet metals.
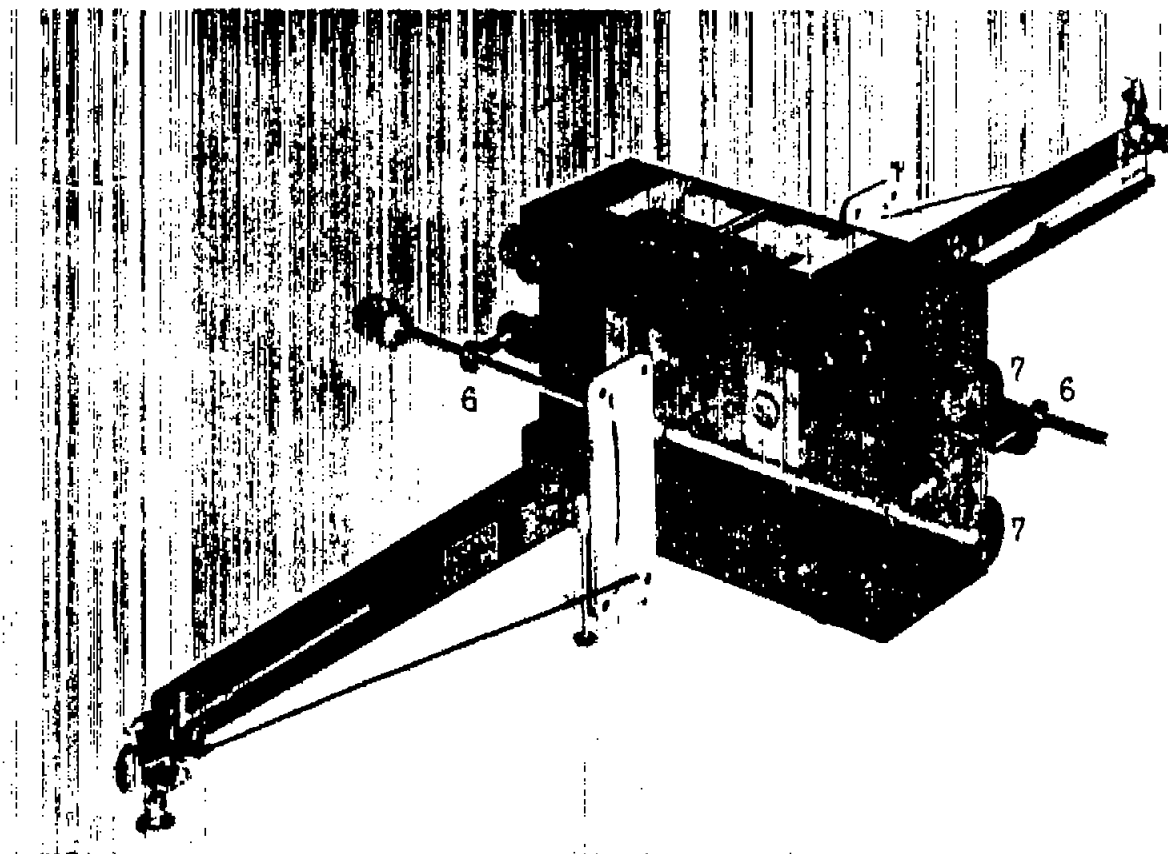(After Mr. W. P. Montgomery, Vought-Sikorsky Aircraft Corp.).

Fig. 2

Figure 3.- Device for making compression tests of single thicknesses of sheet
metals

Dimensions of specimen { length------2.63 in.
width ------0.62 in.
thickness--0.020 in. or more.

Fig. 3
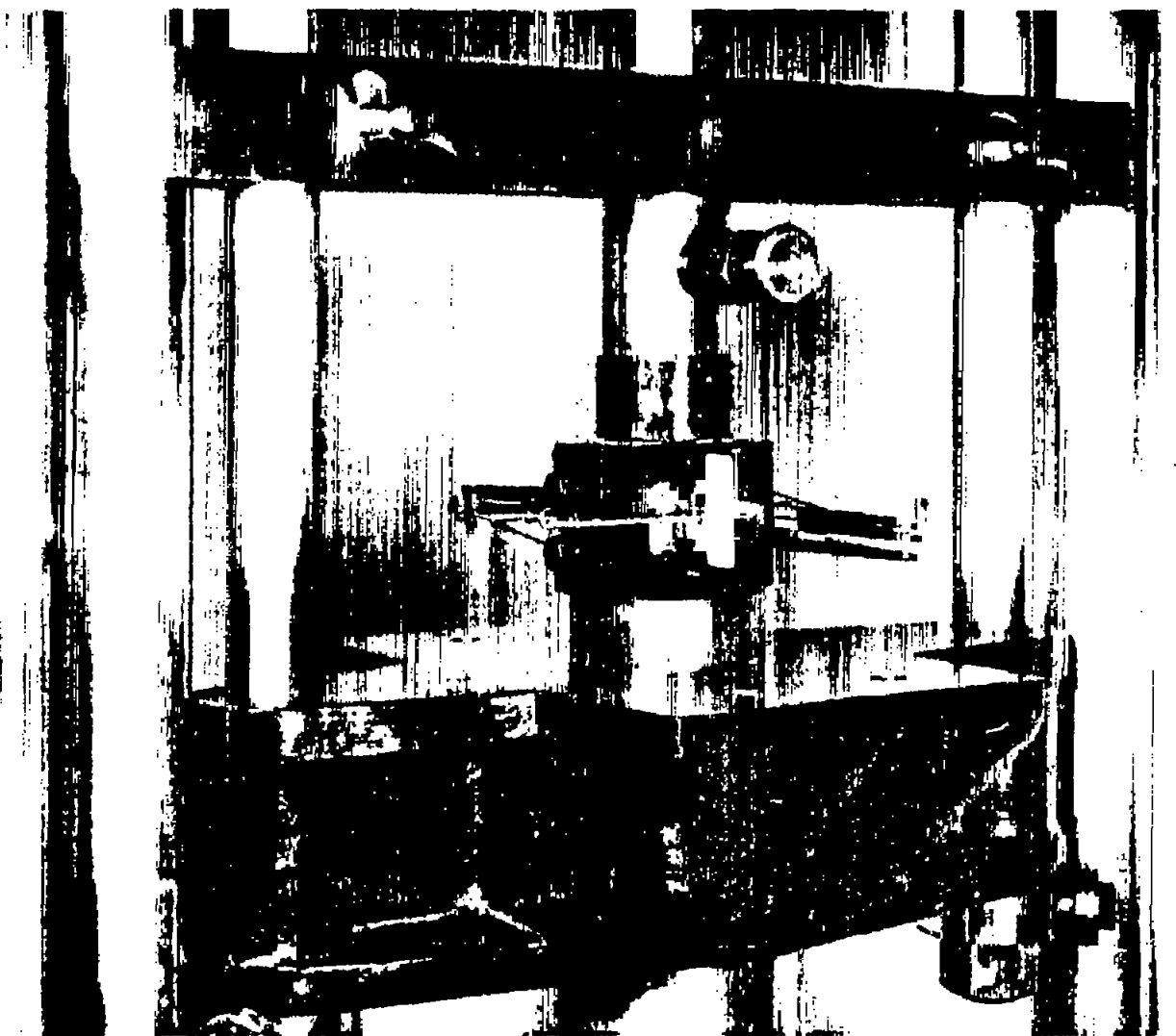
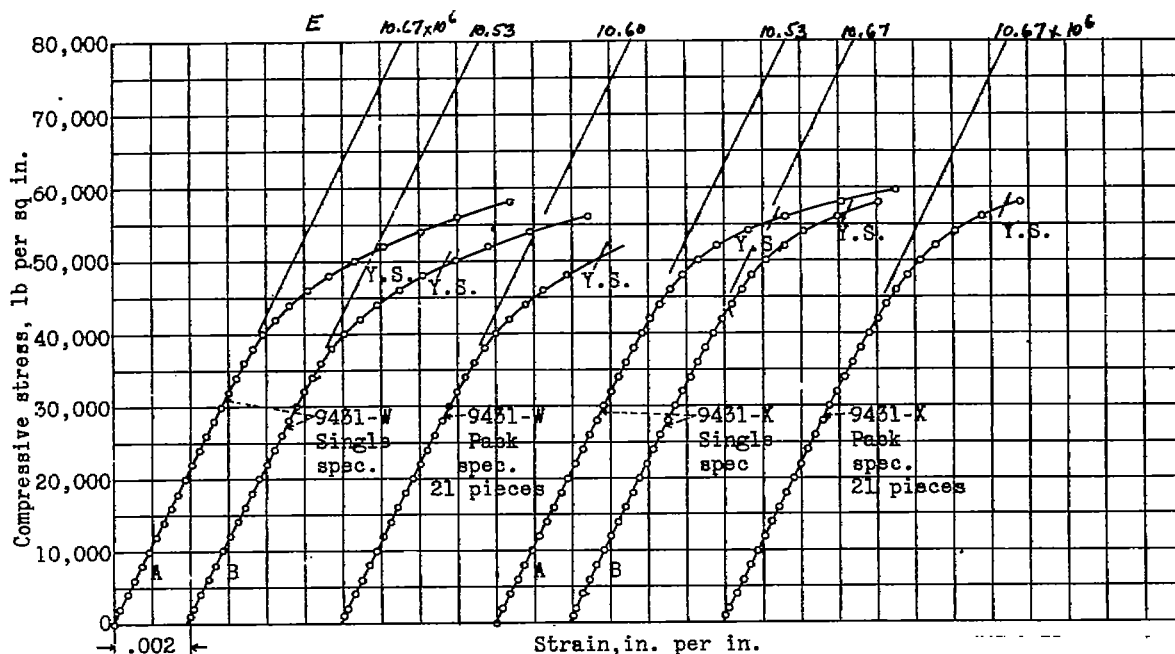Figure 4.- Set-up for testing single thicknesses of sheet metals in compression.
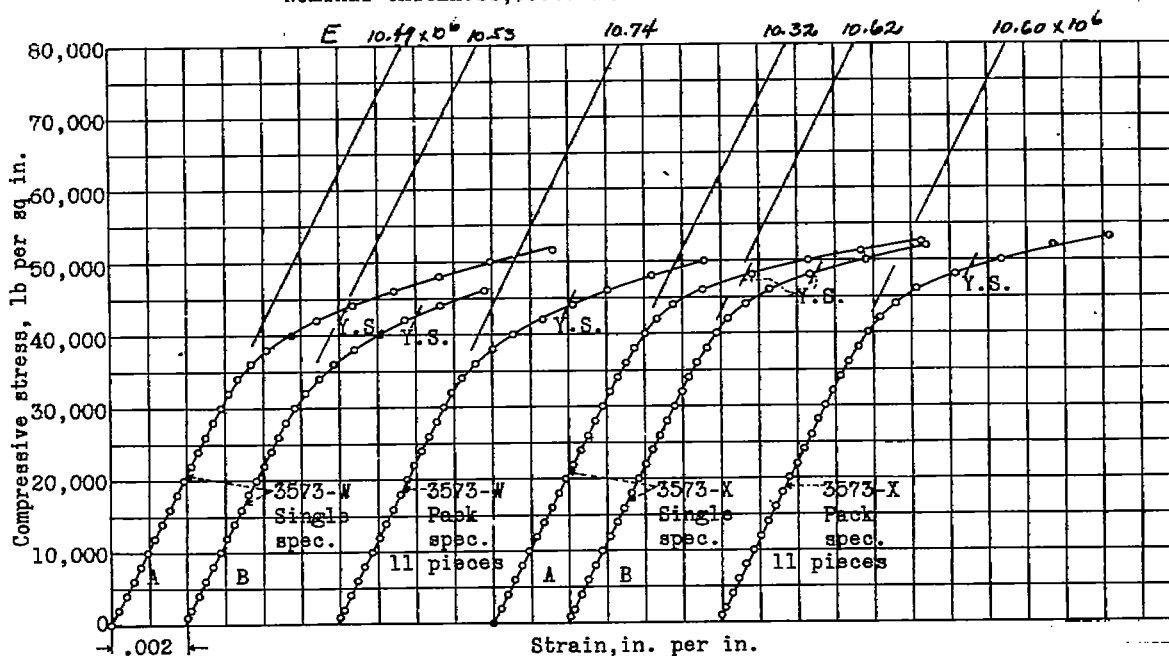
Fig. 4

Figure 5.- Compressive stress-strain curves for 24S-T aluminum-alloy sheet.
Nominal thickness;0.020 inch.

Figure 6.- Compressive stress-strain curves for 24S-T aluminum-alloy sheet.
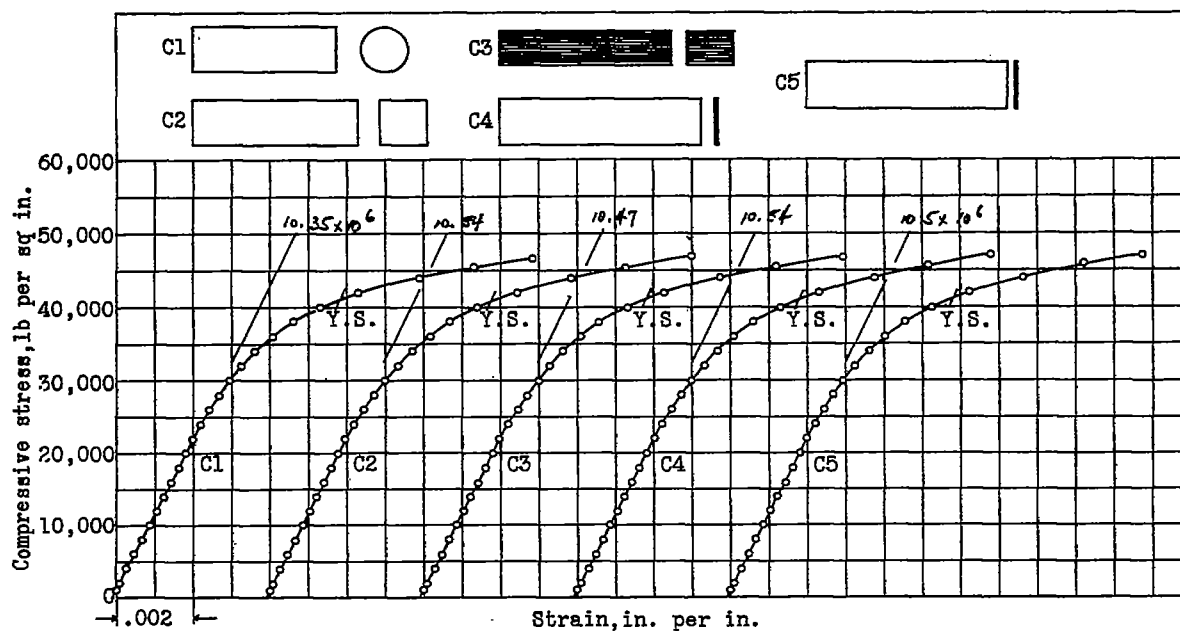Nominal thickness;0.040 inch.

Figure 7.- Compressive stress-strain curves for 17S-T aluminum-alloy plate.
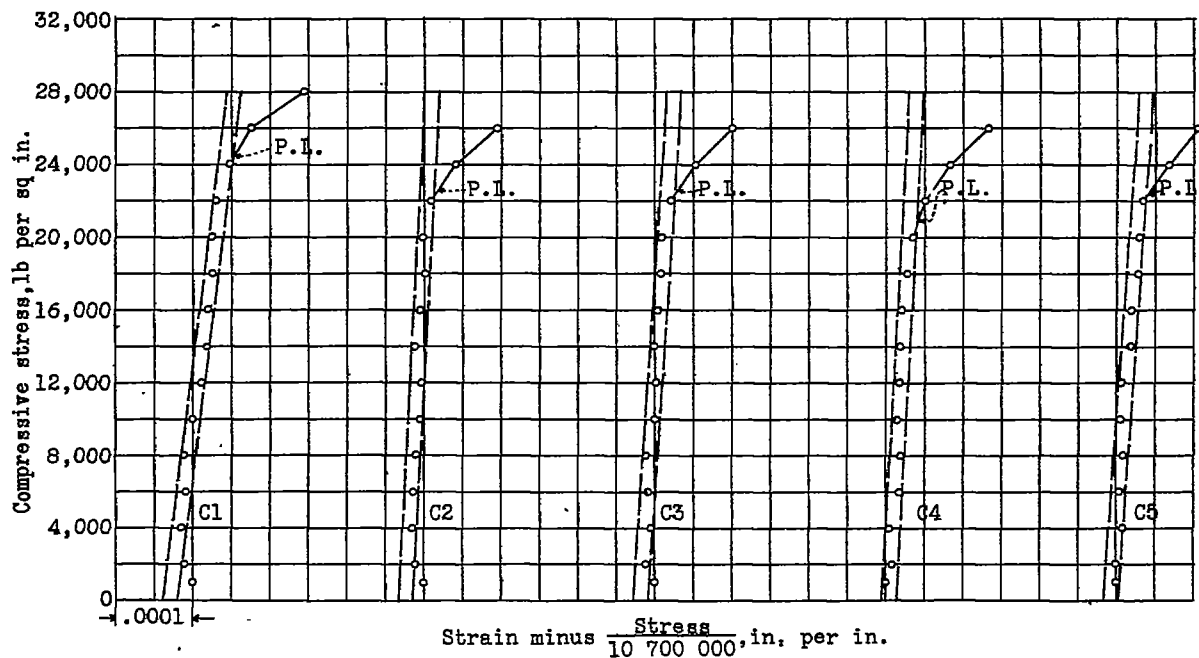

Figure 8.- Differences between observed and computed strains in 17S-T
aluminum-alloy plate.